TRIALS TO DETERMINE THE EFFECTS OF THE ACCIDENTAL IGNITION OF STACKS OF HAZARD DIVISION 1.2 AMMUNITION

M.J.A. Gould,
UK Ministry of Defence, Explosives Storage and Transport Committee

W.D. Houchins,
Naval Surface Warfare Center, Dahlgren Division

ABSTRACT

To date, nearly all international effort in the field of accidental explosion consequence determination has been aimed at the quantification of the effects of a Hazard Division (HD) 1.1 event in an explosives storage facility. Until the commencement of the program of work described here, little attention has been paid to the consequences of the ignition of stacks of Hazard Division 1.2 ammunition either in or out of storehouses.

In 1989 NATO AC/258 agreed that a program of trials should be carried out to investigate the consequences of an HD 1.2 event with the aim of revising the current NATO quantity-distance relationships and placing them on a firmer footing. The program of trials to investigate the effects of the initiation of 105mm TNT loaded ammunition stacked in the open was commenced in 1991. A report on the results obtained at the time was given at the 25th seminar and interim conclusions were drawn.

The program of trials on the TNT loaded ammunition has now been completed and further analysis of the results carried out. The conclusions of the analysis are reported. At the same time, the need was identified to extend the database of effects to examine the consequences of changes in packaging, caliber and type of ammunition, and the explosive fill. The resulting program of trials is described and initial results for the first of these (examining the effects of changing from TNT to Composition B filling in 105mm ammunition) are reported.

BACKGROUND

Interim results from the first five trials of a test program to evaluate the effects of subjecting an exposed stack of HD 1.2 ammunition to a fire environment were reported at the 25th Department of Defense Explosive Safety Board (DDESB) Explosives Safety Seminar[1]. Until that time, most studies conducted to assess the hazards resulting from accidental initiation of large quantities of ammunition had focused on mass detonation of Hazard Division (HD) 1.1 items. Tests such as those carried out in Australia[2-5], France[6], and the United States (US)[7-10] over recent years have assessed the effects of blast and fragment throw from accidental mass detonations in brick and concrete storehouses, igloos, and tunnel magazines.

	Form Approved
Report Documentation Page	*OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **AUG 1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**
4. TITLE AND SUBTITLE **Trials to Determine the Effects of the Accidental Ignition of Stacks of Hazard Division 1.2 Ammunition**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center,Dahlgren Division,6149 Welsh Rd,Dahlgren,VA,22448**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**36**	

Relatively little effort had been devoted to quantifying the effects of the accidental ignition of HD 1.2 ammunition. Unlike HD 1.1 items, HD 1.2 ammunition is not expected to detonate en masse. Instead individual rounds or small clusters of rounds within a stack may explode when sufficiently stimulated (e.g., by fire) without causing others around them to explode. In the case of prolonged events such as fires, explosions may occur intermittently as additional rounds receive sufficient stimulus.

Presently the quantity-distance (Q-D) requirements for storage of HD 1.2 ammunition are different in the US, the United Kingdom (UK), and NATO. The basis for the various international requirements is the definition of the Inhabited Building Distance (IBD). For HD 1.1 mass detonating items, the internationally agreed definition for fragment-related IBD is the range at which fragment areal density reduces to 1 lethal fragment per 600 ft^2, which corresponds to a probability of 0.01 of striking a person. Consideration has been given to using this same criterion for HD 1.2 items. However, sufficient test data to quantify the distribution of fragments from HD=1.2 events were not available. Therefore, in 1989 NATO AC/258 (Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives) determined that a series of bonfire tests should be conducted to investigate the hazards produced by HD 1.2 events. In order to support this effort, the DDESB and the UK Explosives Storage and Transport Committee (ESTC) have funded jointly this series of bonfire tests on selected HD 1.2 items stacked in the open.

A total of six tests using TNT-filled M1 105mm artillery cartridges were completed during the period May 1991 through October 1992. It was recognized that the results from these tests related specifically to the ammunition that was used. Nothing was known about the effects that changes in caliber, explosive fill, or packaging might have. As a result, a series of additional tests was proposed to broaden the experimental database and at least start to look at these effects. Very recently (i.e., May 1994) the first test of this new program was conducted using M1 105mm artillery cartridges that were loaded with Composition B explosive. All seven tests were conducted by the Ordnance Evaluation Branch of the Naval Air Warfare Center, Weapons Division (NAWCWPNS), China Lake, California. The test site was the Cactus Flat Range at NAWCWPNS. This paper summarizes the results of the first six tests (test nos. 1 through 6) and provides analyses of the fragmentation effects. Preliminary results from the most recent test (test no. 7) are reported also; however, the results from this test are still being reviewed and analyses of the fragmentation data are continuing.

TEST PROGRAM

Table 1 summarizes the tests that have been completed thus far. Additional tests using 105mm cartridges loaded with Composition B and 81mm mortar cartridges have been proposed as outlined in Table 2. However, details regarding these additional tests are still being resolved based on availability of test items and funding constraints.

TEST ITEMS

The M1 105mm cartridge is a semi-fixed, high explosive artillery round. The general

configuration of the assembled cartridge is illustrated in Figure 1. The projectile body is fabricated from forged steel and weighs nominally 26 lbs. The propelling charge is comprised of approximately 3 lbs of M1 propellant contained in a spiral wrap steel case. Each propelling charge case weighs approximately 4.7 lbs. Several variants of the M1 cartridge have been produced with projectiles that contain either TNT or Composition B explosive. The cartridges that were used in test nos. 1 through 6 contained TNT explosive as the projectile main fill. Each of these cartridges was also assembled with an aluminum closure plug instead of a live fuze. The cartridges that were used in test no. 7 contained Composition B explosive as the projectile main fill. When received from the supply depot, these cartridges were assembled with live mechanical time fuzes. The fuze was removed from each cartridge prior to the test to comply with range safety requirements. Each fuze well was left open during the test.

The cartridges are packaged in wooden boxes for transport and storage. Each box contains two cartridges that are packaged individually in fiberboard sleeves as shown in Figure 2. The cartridges are oriented such that the projectile of one cartridge is adjacent to the propelling charge of the other cartridge (i.e., nose-to-tail arrangement). The boxes are palletized on wooden pallets. A complete pallet contains 15 or 16 boxes depending on their arrangement. The boxes are secured on the pallet using steel banding.

TABLE 1. TESTS COMPLETED USING PALLETS OF M1 105MM CARTRIDGES

Test No.	Projectile Explosive Fill	No. Pallets[*]	No. Rounds
1	TNT	1	30
2	TNT	1	30
3	TNT	1	30
4	TNT	8	240
5	TNT	8	240
6	TNT	27	864
7	Composition B	3	96

[*] NOTE: Test nos. 1 through 5 were conducted using pallets that contained 30 rounds (15 boxes) each. Test nos. 6 and 7 were conducted using pallets that contained 32 rounds (16 boxes) each.

TABLE 1.
TESTS COMPLETED USING PALLETS OF M1 105MM CARTRIDGES

TABLE 2. PROPOSED ADDITIONAL TESTS

Test Items	Warhead Fill	Packaging Configuration	No. Pallets Per Test	No. Rounds Per Test	No. Tests
M1 105mm cartridges	Composition B	Wooden boxes	3	96	1
M374A2 81mm mortar rounds	Composition B	Wooden boxes	2	180	2
M374A2 81mm mortar rounds	Composition B	Metal boxes	2	180	2

TABLE 2. PROPOSED ADDITIONAL TESTS

FIGURE 1. M1 105MM CARTRIDGE
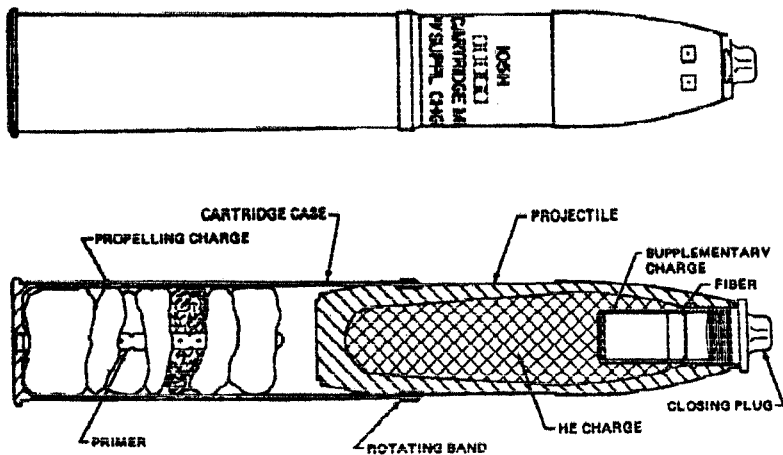
Nominal Characteristics

Projectile Body:	Forged Steel
Projectile Body Weight:	26 lb
Explosive Fill (HE charge):	TNT or Composition B
Explosive Weight (HE charge):	4.6 lb
Propelling Charge Case:	Spiral Wrap Steel
Propellant:	M1 Propellant
Propellant Weight:	2.8 lb
Net Explosive Weight (total)	7.4 lb

FIGURE 1. M1 105MM CARTRIDGE
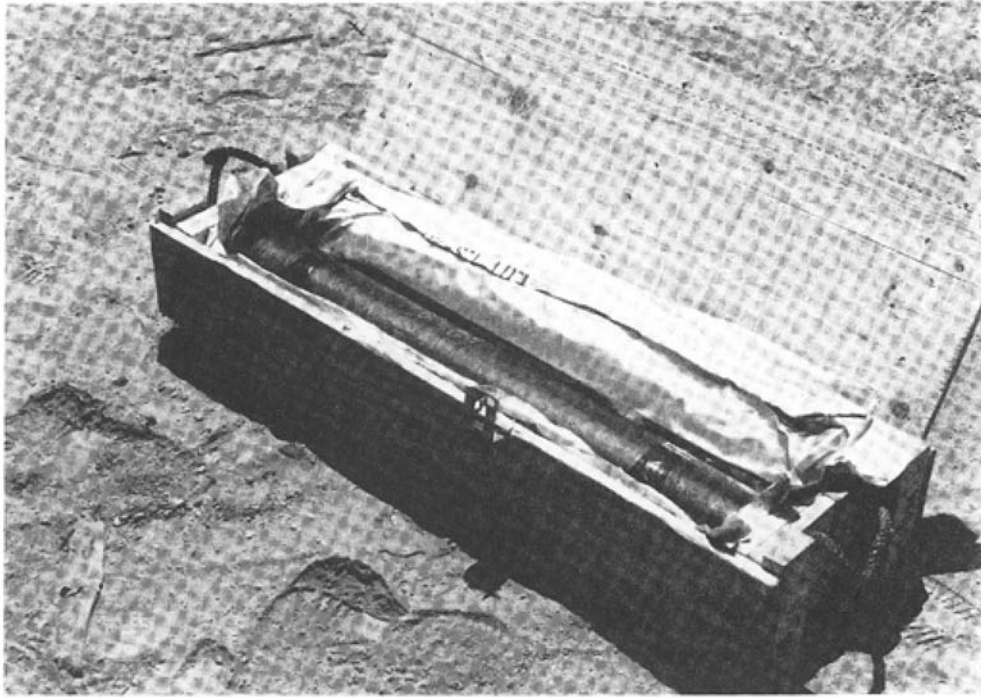
FIGURE 2. PACKAGING OF M1 105MM CARTRIDGES

FIGURE 2. PACKAGING OF M1 105MM CARTRIDGES

TEST METHOD

<u>Test Configurations</u>

The first four tests were conducted generally in accordance with the methodology prescribed by the UN Recommendations on the Transport of Dangerous Goods[11]. The test items were stacked on a steel test stand that provided approximately 30 inches clearance between the bottom of the stack and ground level. The top of the test stand was constructed as shown in Figure 3 to function as a grate. Dried lumber placed beneath the test stand and around the pallet(s) was used as kindling to provide fuel during the initial stages of the test. Four shallow steel troughs containing a small amount of gasoline (less than 5 gallons each) were placed around the base of the stack to provide an ignition source for the fire. The gasoline in the troughs was ignited using an electric squib. In order to eliminate ground cratering and burrowing of unexploded test items at the stack site (ground zero), the stack was constructed over a concrete pad. The top of the concrete pad was protected by a steel plate. A typical completed test setup is shown in Figure 4.

Test nos. 5 through 7 were conducted in the same manner except that kindling was placed beneath the test stand only. This was done to more realistically simulate an accident scenario in which the test item packaging materials and the energetic components are the primary fuel source for a fire. For example, it was determined that the total volume of wood present in test no. 4 was comprised of approximately 64% kindling and 34% test item packaging (i.e., boxes and pallets). The corresponding ratio for test no. 5 was approximately 43% kindling and 57% test item packaging. One other change made for test nos. 6 and 7 was omission of the steel plate used to protect the concrete pad. The completed test setup for test no. 5 is shown in Figure 5.

The 8-pallet tests (i.e., test nos. 4 and 5) were conducted with the pallets arranged in a 2x2x2 matrix. The 27-pallet test (i.e., test no. 6) was conducted using a 3x3x3 stacking arrangement. Test no. 7 was conducted with two pallets at the base of the stack and the third pallet centered on top as shown in Figure 6.

The tests were conducted on a flat, dried lake bed. The debris recovery area encompassed a full 360º azimuthally about ground zero. It was scraped clear of virtually all vegetation to a range of 1300 ft. In order to facilitate recovery of the test item debris, this cleared region was marked with a 10º x 200 ft grid. Recovery of the test item debris was accomplished manually through systematic visual searches of the area by test personnel. The debris that were recovered inside the 200 ft range were not retained for analyses due to their large numbers. However, these debris were segregated according to type (i.e., projectile case piece, cartridge case piece, or miscellaneous) and the total weight of all pieces of each type was determined. The pieces of debris that were recovered beyond the 200 ft range were identified according to the grid sector in which they were found. The post test searches were limited to a range of 2000 ft. On-site observations and review of the video records indicated that few, if any, fragments were impacting at ranges greater than 2000 ft. Thus recovery beyond this range was not considered cost effective because the numbers of fragments were judged to be too

small to justify the time and manpower required to search such a vast area. Additionally, the likelihood of finding any of the few fragments that might lie in this region was considered low due to the presence of vegetation.
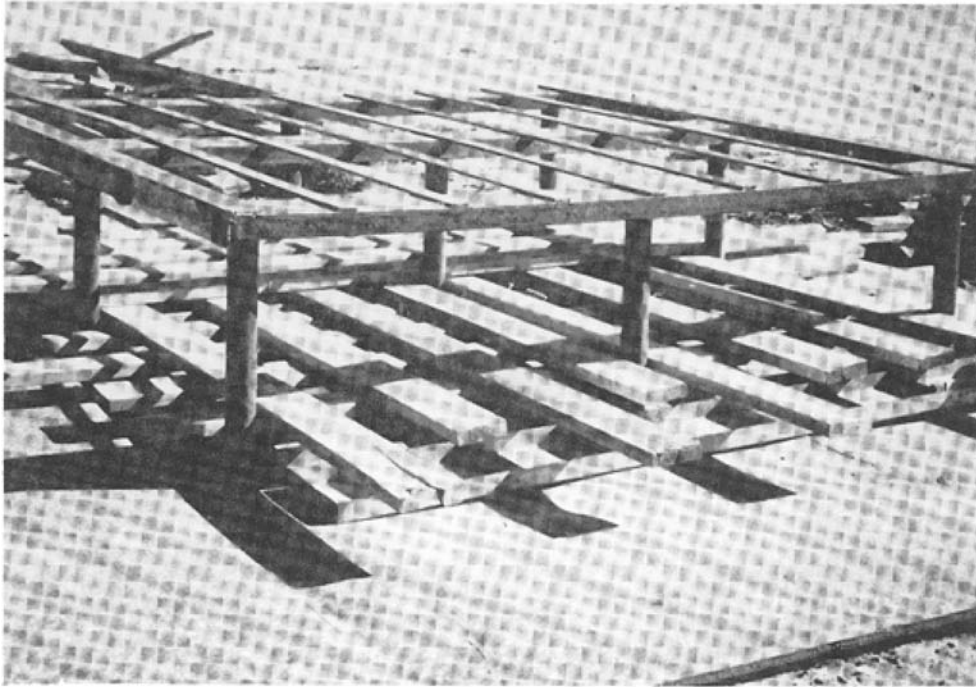
FIGURE 3. CONSTRUCTION OF TEST STAND

FIGURE 3. CONSTRUCTION OF TEST STAND

FIGURE 4.
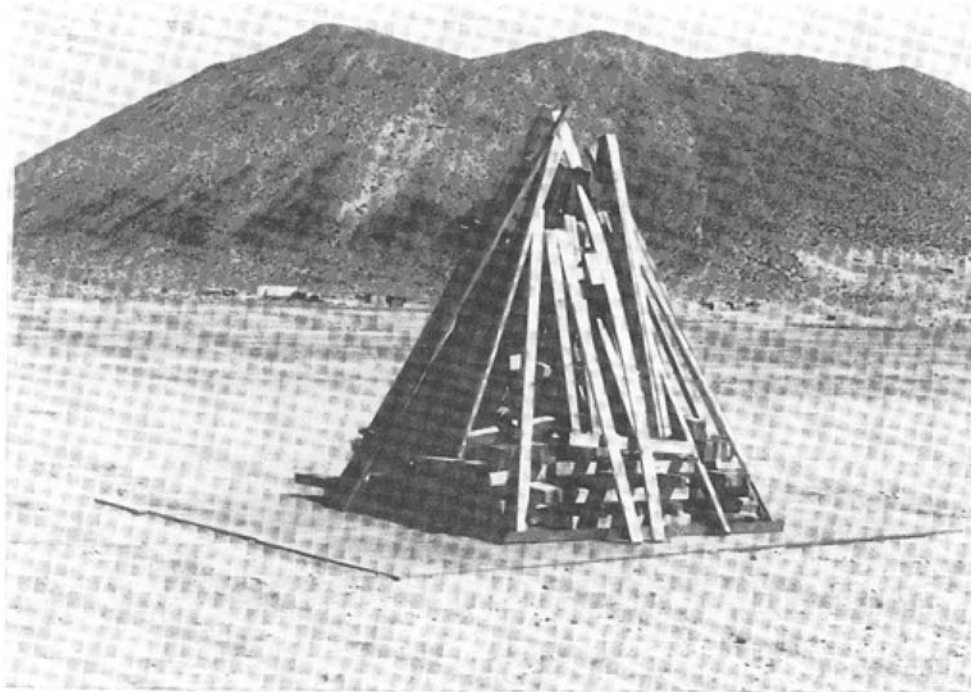# TYPICAL COMPLETED SETUP FOR TEST NOS. 1 THROUGH 4

FIGURE 4. TYPICAL COMPLETED SETUP FOR TEST NOS. 1 THROUGH 4
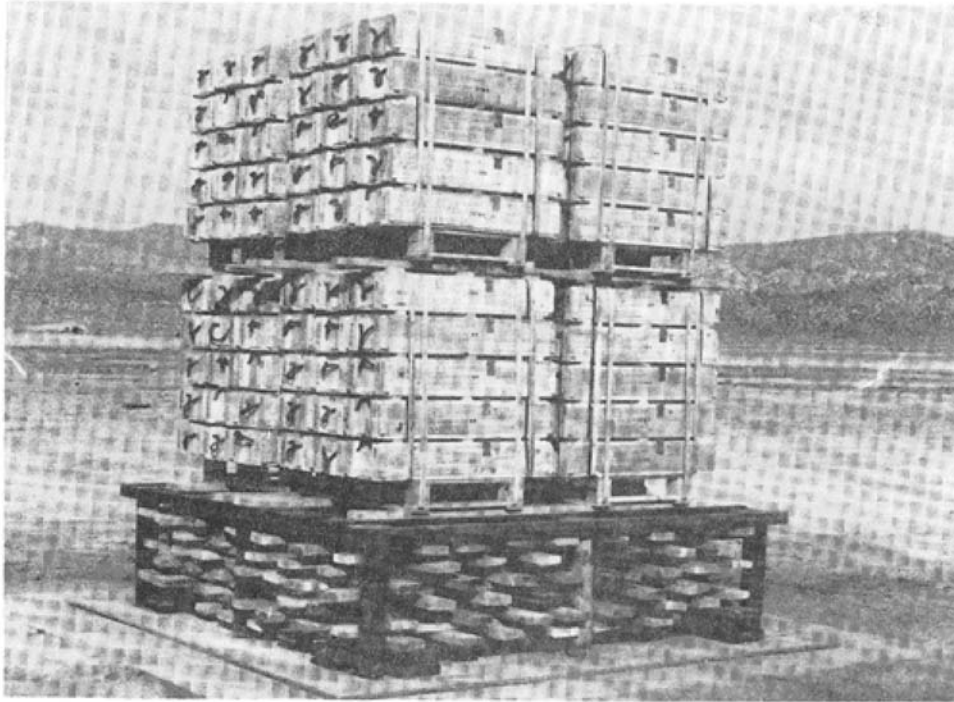
FIGURE 5. COMPLETED SETUP FOR TEST NO. 5

FIGURE 5. COMPLETED SETUP FOR TEST NO. 5

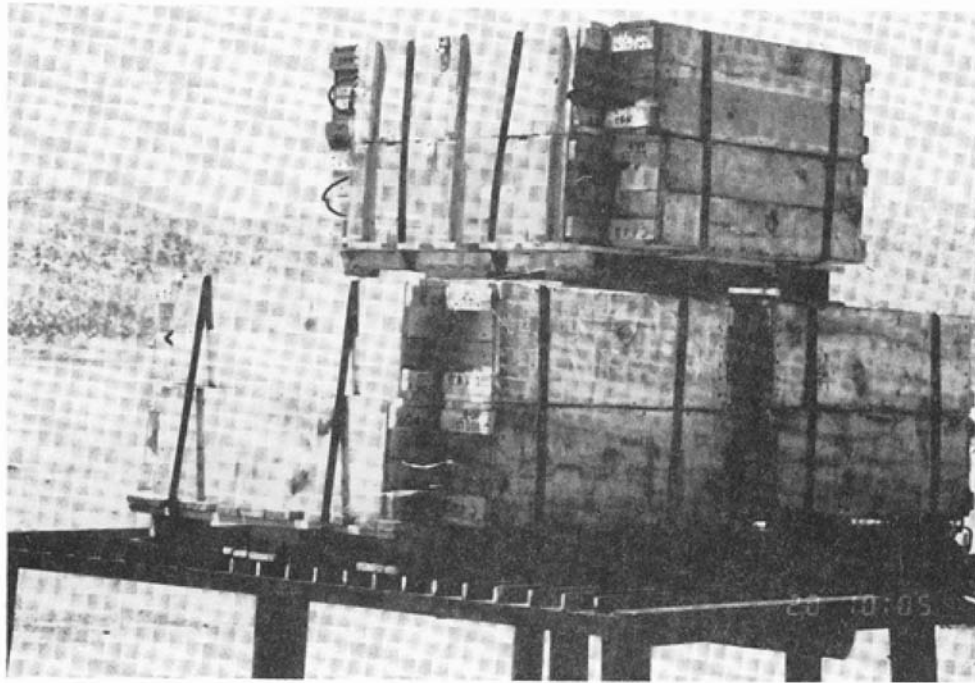# FIGURE 6. STACKING ARRANGEMENT FOR TEST NO. 7

FIGURE 6. STACKING ARRANGEMENT FOR TEST NO. 7

<u>Instrumentation</u>

Blast overpressures were measured during test nos. 2 through 7 to support assessments of the number of projectile explosions that occurred in each test. Temperatures were measured at selected points within the stack during test nos. 6 and 7 using shielded type K thermocouples. Detailed descriptions of the instrumentation systems, pressure and temperature records, and analyses of the instrumentation data from test nos. 1 through 6 are provided in another report[12]. The instrumentation data from test no. 7 are still being analyzed at this time.

The test events were recorded using closed circuit video systems. Typically, one to three video cameras were positioned approximately 500 ft from the test stack to record the events that occurred within the immediate confines of the fire. Additional video cameras were positioned on hillsides overlooking the test area to record the general location of larger debris as it impacted the ground. An attempt was also made during each of the first four tests to determine the terminal flight characteristics (e.g., velocity, angle of fall, etc.) of fragments impacting within a selected sector by capturing their terminal stages of flight on video. However, a fragment impacted within the selected sector in only one test and in that instance the image size of the fragment was below the resolution of the video record.

OBSERVATIONS AND RESULTS

 General observations for each test are summarized in Table 3.

Test nos. 1 through 6 produced similar results with respect to fire buildup, onset of test item reactions, levels of test items reactions, and event duration. In each test the fire developed rapidly following ignition with the entire stack being engulfed within three to five minutes. Relatively mild test item reactions were usually observed about 15 to 20 minutes after ignition of the fire. These relatively mild initial reactions were followed a short time later (i.e., usually within 5 minutes) by a series of much more violent explosion reactions that occurred intermittently throughout the remainder the test intermingled with additional mild reactions. Typically, the fire would continue to burn at full intensity only until the first few explosions had occurred. It would then begin to die out slowly due to scattering of the stack by each successive explosion. In all tests the fire was reduced to broadly scattered smoldering debris in less than one hour. However, in each test, one or more explosions were observed after the fire was effectively out.

TABLE 3. GENERAL OBSERVATIONS FOR EACH TEST

Test No.	Stack Size (No. of Cartridges)	Elapsed Time to Initial Reaction (min:sec)	Elapsed Time to First Explosion (min:sec)	No. of Explosions	Elapsed Time to Last Explosion (min:sec)	No. of Projectile Bodies Recovered Intact
1	30	15:32	18:24	13	48:53	17
2	30	20:22	24:14	9	42:36	21
3	30	20:05	36:48	11	78:40	18 *
4	240	18:13	20:48	66	61:08	174
5	240	14:15	18:37	65	41:43	174
6	864	21:11	25:54	324**	73:39	546
7	96	23:48	31:38	8	51:58	82

* A 19th projectile body was recovered with only minor damage in the nose region (i.e., small fracture).

** The frequency of explosions was so great at times that the number of explosions could not be determined from visual observation or video records. Pressure records indicated a total of 324 events that produced measurable overpressures, however some events were attributed to propelling charge reactions (reference 12).

TABLE 3. GENERAL OBSERVATIONS FOR EACH TEST

The fire buildup in test no. 7 was somewhat more gradual than that observed in the first six tests. The fire was disturbed by a persistent light breeze during the initial portion of the test and complete engulfment of the stack did not occur until approximately 10 minutes after the start of the test. Relatively mild test item reactions were observed approximately 23:48 (min:sec) after ignition of the fire and continued intermittently throughout the test. A total of eight major explosions were observed at approximately the following times: 31:38, 35:43, 38:08, 40:01, 40:08, 40:40, 43:11, and 51:58.

The relatively mild reactions observed in each test were characterized by intense burning of energetic material that was accompanied occasionally by a small flash and/or low level report (pop). These reactions are presumed to have been mild deflagrations of the propelling charges and/or burning of the explosive fill in some projectiles resulting in failure of the nose plug and sudden venting of the reaction gases. It appeared, based on visual observations, that most of the debris that were ejected from the bonfire following one of these reactions had very limited range; less than 100 ft in most instances. The much more violent reactions were presumed to be explosions of projectiles and were characterized by abrupt instantaneous expansion of the fire, low level air shock, a loud audible report, and scattering of burning wood and other debris about the test site. Pieces of debris were seen impacting the ground at ranges approaching or even exceeding 1000 ft following some of these explosions.

It appeared that most of the explosion reactions occurred within 50 ft of ground zero. Neither on-site observations nor video records provided any indications of test items being thrown beyond the 200 ft range and then exploding after ground impact. However, there were some instances in which burning projectiles were thrown into the far-field where they continued to burn after impact . Additionally, at least one unreacted projectile was recovered more than

200 ft from ground zero following each test, with the exception of test no. 2. The estimated locations of the explosion reactions in test no. 6 are shown in Figure 7[12]. It can be seen that only two of the locations are more than 50 ft from ground zero.

The azimuthal and radial distributions of fragments recovered beyond the 200 ft range (far-field fragments) after test nos. 4, 6, and 7 are illustrated in Figures 8 through 10, respectively. These distributions are representative of all of the tests in that the fragments were distributed randomly with respect to azimuthal angle and all of the fragments were recovered inside the 2000 ft range. To date only one fragment has been recovered at a range greater than 2000 ft. An on-site observer saw the fragment impacting the ground during test no. 5. The fragment was recovered afterwards at a range of 3140 ft . It is speculated that this particular fragment, rather than tumbling randomly in flight, experienced a flat rotation that minimized drag and created significant lift throughout most of its trajectory (i.e., Frisbee effect).

Figure 11 shows some typical projectile body fragments that were recovered beyond the 200 ft range after test nos. 1 through 6. Nearly all projectile case fragments from these tests appeared to have been produced by explosion reactions in which the projectile body broke into a small number (i.e., less than 10) of relatively large pieces. However, 15 fragments were recovered after test no. 6 that appeared to have been produced by detonation reaction(s). Figure 12 shows some typical projectile body fragments that were recovered after test no. 7. Seventy-four of the 130 projectile body fragments recovered after this test appeared to have been caused by detonation reaction(s).

FIGURE 7.
APPROXIMATE LOCATIONS OF EXPLOSIONS IN TEST NO. 6
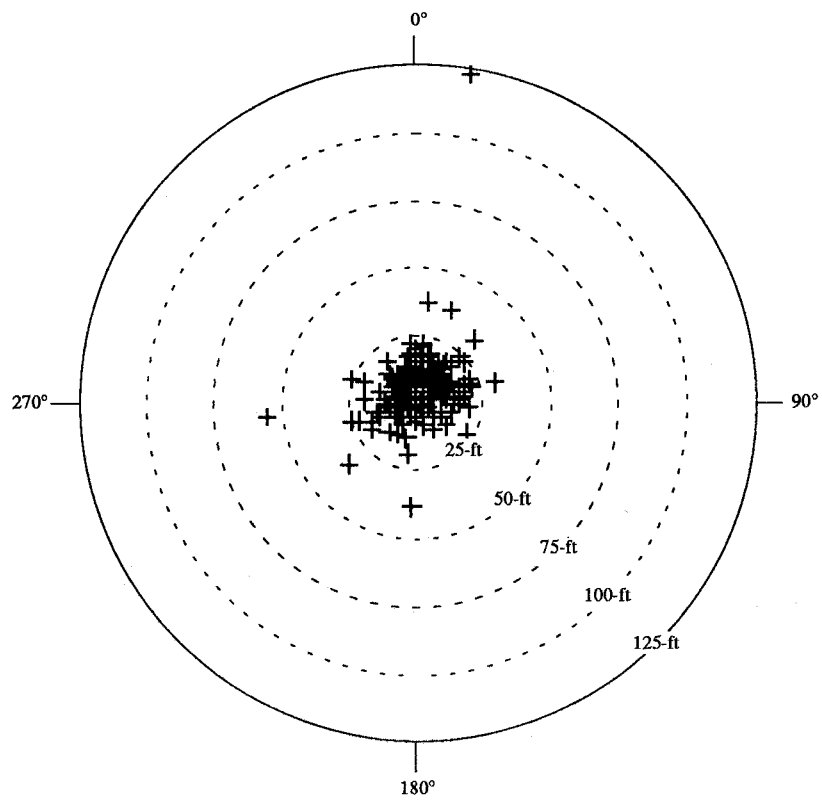
FIGURE 7. APPROXIMATE LOCATIONS OF EXPLOSIONS IN TEST NO. 6

FIGURE 8.
APPROXIMATE DISTRIBUTION OF FRAGMENTS AFTER TEST NO. 4
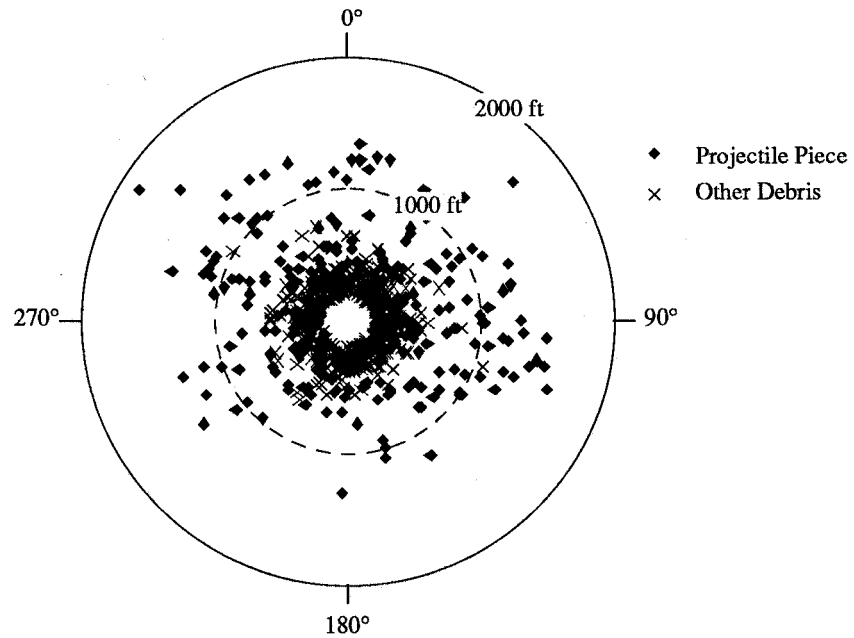
FIGURE 8. APPROXIMATE DISTRIBUTION OF FRAGMENTS AFTER TEST NO. 4

FIGURE 9.
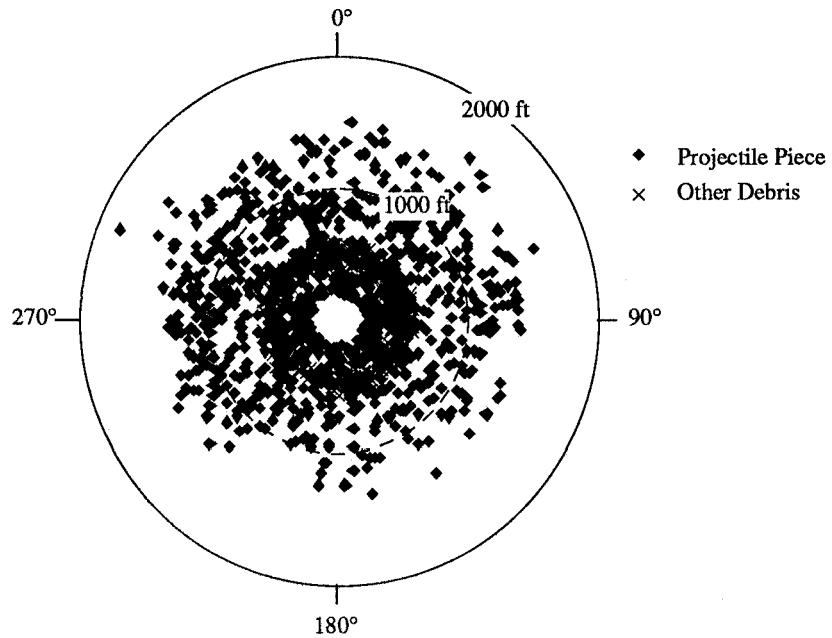## APPROXIMATE DISTRIBUTION OF FRAGMENTS AFTER TEST NO. 6

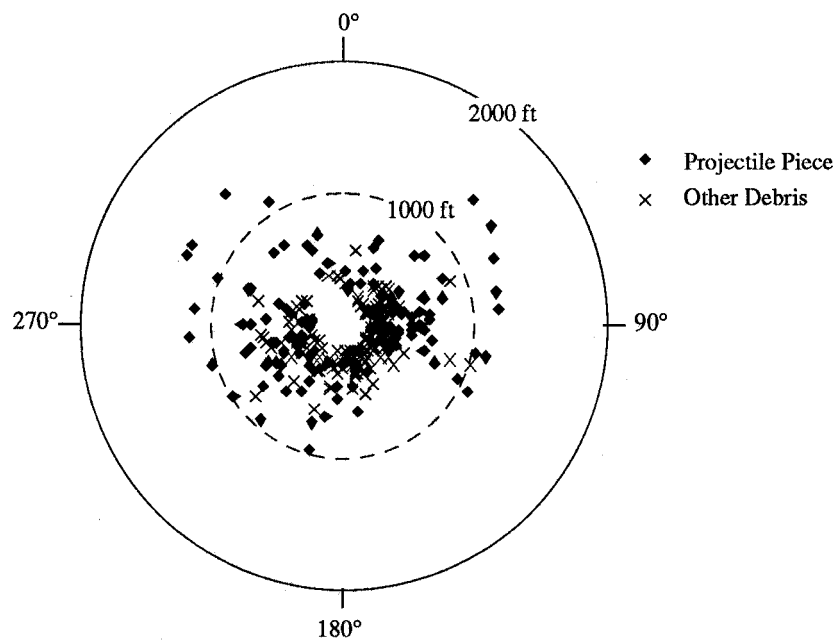FIGURE 9. APPROXIMATE DISTRIBUTION OF FRAGMENTS AFTER TEST NO. 6

FIGURE 10. APPROXIMATE DISTRIBUTION OF FRAGMENTS AFTER TEST NO. 7

FIGURE 10. APPROXIMATE DISTRIBUTION OF FRAGMENTS AFTER TEST NO. 7

FIGURE 11. TYPICAL PROJECTILE FRAGMENTS RECOVERED BEYOND 200 FT RANGE AFTER TEST NOS. 1 THROUGH 6
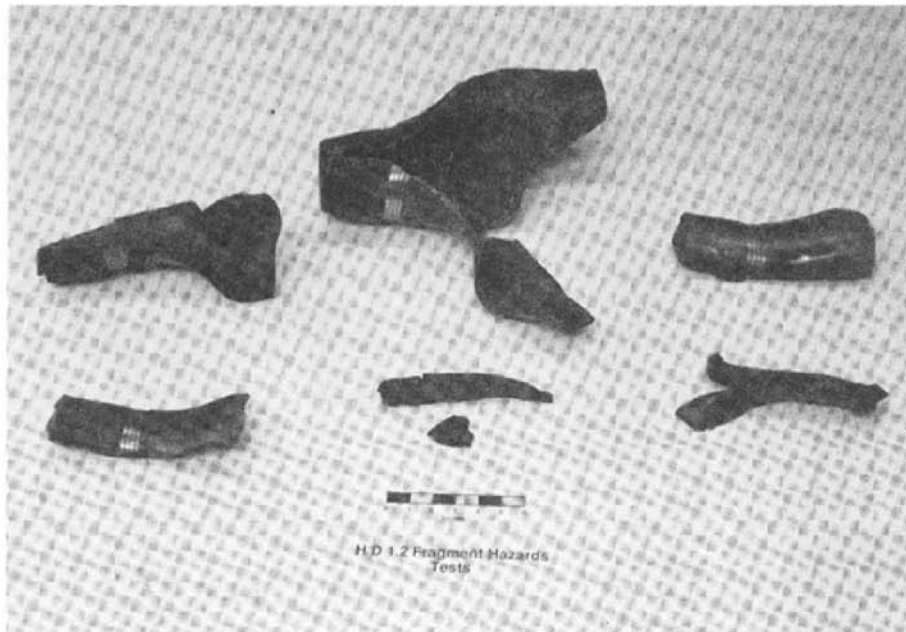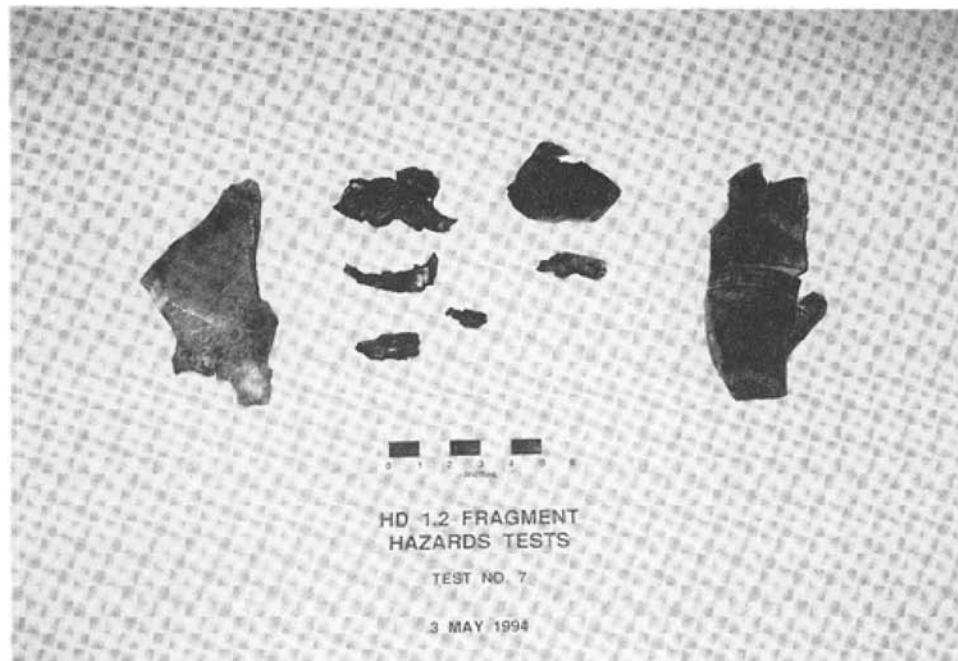

FIGURE 11. TYPICAL PROJECTILE FRAGMENTS RECOVERED BEYOND 200 FT RANGE AFTER TEST NOS. 1 THROUGH 6

FIGURE 12. TYPICAL PROJECTILE FRAGMENTS RECOVERED BEYOND 200 FT RANGE AFTER TEST NO. 7

HD 1.2 FRAGMENT
HAZARDS TESTS

TEST NO. 7

3 MAY 1994

FIGURE 12. TYPICAL PROJECTILE FRAGMENTS RECOVERED BEYOND 200 FT RANGE AFTER TEST NO. 7

ANALYSES

It is apparent, based on visual observations, that the primary hazard associated with these HD 1.2 events is flying debris. Except for a small region in the immediate vicinity of the fire, air shock and firebrands do not appear to be a significant hazard. Therefore, the objective of this analysis is to characterize the fragment hazard associated with various size stacks of 105mm cartridges. In general, this has been accomplished by describing the hazard in terms of fragment areal densities in a manner analogous to that used to establish hazard ranges for HD 1.1 items. As discussed previously, it is proposed that the same fragment areal density criterion that is used to establish IBD's for HD 1.1 items (i.e., 1 hazardous fragment per 600 ft^2) may be applied to the M1 105mm cartridge and other similar HD 1.2 items.

The following analysis is based primarily on the results of tests nos. 1 through 6 (i.e., TNT-filled cartridges). The results from test no. 7 are still being evaluated; however, some preliminary results are provided to permit initial comparisons between the two test item configurations.

The analysis is based on several underlying observations and/or assumptions:

a. The fragment recovery data for these analyses have not been subjected to rigorous statistical tests. However, inspection of Figures 8 through 10 suggests that the distribution of far-field fragments with respect to azimuthal angle about the stack is fairly random. Therefore, it has been assumed that the azimuthal distribution of fragments is uniform (i.e., there are no directional effects) and thus fragment areal densities may be assessed as a function of range only.

b.   Since there are no means to determine the trajectory of a fragment (and thus its kinetic energy) based on its range, all recovered fragments were assumed to be hazardous (i.e., >58 ft-lb kinetic energy). This includes numerous cartridge case pieces and miscellaneous debris recovered within the 200 ft to 400 ft range interval that had individual masses as low as 0.01 lb$_m$.

c. With only a few exceptions, projectile case pieces were the only type of debris recovered more than 600 ft from ground zero. This suggests that projectile explosions are the primary contributor to far-field fragment hazards. Thus, far-field fragment areal densities are expected to be dependent on the number of projectiles that explode rather than the total number of rounds in the stack (i.e., stack size). However, the number of projectiles that explode does generally increase with stack size.

d. The percentage of projectiles that explode is somewhat variable. In the tests of TNT-filled cartridges, the percentage of projectiles that exploded ranged from a minimum of 27.1% in test no. 5 to a maximum of 43.3% in test no. 1. In contrast, only 14.6% of the projectiles exploded in the one test conducted using cartridges filled with Composition B.

e. Based on analyses of the masses of fragments that were recovered after each test, the fragment recoveries were somewhat incomplete for all tests except test no. 6. This is particularly true for the projectile case fragments which, as indicated previously, were the only type of debris to have significant ranges. Calculation of the approximate percentage of recovery for each test is outlined in Table 4.

Analyses of the test data were accomplished in the following manner. First the fragment recovery data for each test were adjusted to compensate for the apparent shortfalls in the far-field recovery. For each test the total mass of all far-field projectile fragments that were generated (m_f) and the corresponding portion of far-field fragments that were actually recovered (P_{rec}) were estimated as:

$$m_f = (N_t - N_i)m_p - m_0$$ where: N_t is the number of cartridges tested
N_i is the number of projectile bodies recovered intact
m_p is the mass of each projectile body (26 lb)
m_0 is the total mass of projectile pieces recovered inside 200 ft

$$P_{rec} = m_r/m_f$$ where: m_r is the mass of all recovered far-field projectile fragments

The total number of projectile case fragments for each range interval was then scaled up as:

$$n_{scaled} = n_r/P_{rec}$$ where: n_r is the number of projectile case pieces recovered

This adjustment was applied for projectile case pieces only. The recovery data indicate very few pieces of any other debris were recovered beyond a range of a few hundred feet. Thus, the contribution of these other debris to far-field fragment hazards is minimal and no adjustment appears warranted. Table 5 summarizes the adjusted total fragment counts for each test.

The adjusted fragment recovery data for each test were used to determine an average number of fragments in each range interval that were generated by each projectile explosion (fragments/explosion). These data are presented in Table 6. For test nos. 1 through 6, the maximum envelope of these data were then used to predict the number of fragments expected in each range interval for larger stacks of TNT-filled cartridges. Two cases were modeled. In one case it was assumed that 45% of the projectiles in the stack would explode. This assumption is believed to be slightly conservative based on the tests conducted to date. In the other case it was assumed that all of the projectiles in the stack would explode; a worst case condition. The results from test no. 7 were used in a similar manner to predict the number of fragments in each range interval for larger stacks of cartridges containing Composition B. However, the two conditions considered were (a) 14.7% of the projectile explode, as observed in test no. 7, and (b) 100% of the projectiles explode.

For each selected stack size the areal density of fragments for each range interval was

calculated as the total fragment count for the range interval divided by the area of the corresponding annulus. Pseudo trajectory-normal methods were used to determine the fragment count for each range interval[13]. Essentially this means that the fragment count for a given range interval includes the number of fragments that are expected to fall within that range interval plus the number of fragments that are expected to pass through the range interval and fall beyond the range interval.   As an example, Table 7 outlines the calculation of the predicted fragment areal densities for a stack containing 1000 TNT-filled cartridges.

The density-range estimates for each selected stack size were then fitted using cubic spline fits to determine the ranges at which the areal density of fragments would exceed one fragment per 600 ft^2. Determination of the estimated ranges to exceed one fragment per 600 ft^2 for a stack of 1000 TNT-filled cartridges is illustrated in Figure 13. Table 8 presents the estimated ranges to exceed one fragment per 600 ft^2 (predicted 1/600 ranges) for various size stacks of each configuration of test items. These ranges are shown graphically in Figures 14 and 15. The IBD's prescribed by current NATO/UK and US Q-D requirements for HD 1.2 items are provided in Figures 14 and 15 for comparison.

TABLE 4. ESTIMATION OF PERCENTAGES OF RECOVERY

	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Test No. 5	Test No. 6	Test No. 7
No. of Cartridges in Stack:	30	30	30	240	240	864	96
Recovery of Projectile Body Pieces:							
Intact Projectile Bodies Inside 200 ft Range:	16	21	15	164	167	493	80
Intact Projectile Bodies Beyond 200 ft Range:	1	0	3	10	8	53	2
Total No. of Intact Projectile Bodies:	17	21	18	174	175	546	82
No. of Projectile Bodies that Fragmented:	13	9	12	66	65	318	14
Approximate Weight of Projectile Pieces (lb): (Based on projectile body mass of 26 lb each)	338	234	312	1716	1690	8268	364
Mass of Projectile Pieces Recovered Inside 200 ft Range:	118.5	66	85.625	754	879	5400	124.6
Approximate Total Weight of Projectile Pieces With Range Greater Than 200 ft Range (lb): (Assumes 100% recovery inside 200 ft range)	219.5	168	226.375	962	811	2868	239.4
Total Weight of Projectile Body Pieces Recovered Beyond 200 ft Range (lb):	139.6	153.5	140.5	600.4	612.9	3136.7 (note 2)	164.6 (note 3)
% Recovery of Projectile Body Pieces With Range Greater Than 200 ft:	64%	91%	62%	62%	76%	109%	69%
% Recovery of All Projectile Body Pieces:	76%	94%	72%	79%	88%	103%	79%
Recovery of Cartridge Case Pieces:							
Total Weight of Cartridge Case Pieces (lb): (Based on cartridge case mass of 4.7 lb each)	141	141	141	1128	(note 1)	(note 1)	(note 1)
Mass of Cartridge Case Pieces Recovered Inside 200 ft Range:	130.0	136.3	134.5	874.0	(note 1)	(note 1)	(note 1)
Approximate Weight of Cartridge Case Pieces With Range Greater Than 200 ft (lb): (Assumes 100% recovery inside 200 ft range)	11	4.7	6.5	254	(note 1)	(note 1)	(note 1)
Total Weight of Cartridge Case Pieces Recovered Beyond 200 ft Range (lb):	5.39	2.52	4.12	92.26	(note 1)	(note 1)	(note 1)
% Recovery for Cartridge Case Pieces With Range Greater Than 200 ft:	49%	54%	63%	36%	(note 1)	(note 1)	(note 1)
% Recovery for All Cartridge Case Pieces:	96%	98%	98%	86%	(note 1)	(note 1)	(note 1)

NOTES: 1. The total mass of the cartridge case pieces recovered was not determined. The results of test nos. 1 through 4 indicated that nearly all of the cartridge case pieces could be accounted for.
2. Extrapolated weight based on limited recovery beyond 1300 ft range. The posttest search for test no. 6 was limited to 150° azimuthally for ranges greater than 1300 ft.
3. Extrapolated weight based on limited recovery beyond 1300 ft range. The posttest search for test no. 7 was limited to 60° azimuthally for ranges greater than 1300 ft.

TABLE 4. ESTIMATION OF PERCENTAGES OF RECOVERY

TABLE 5. ADJUSTED FRAGMENT COUNTS

Total No. of Fragments

Range Interval (ft)	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Test No. 5	Test No. 6	Test No. 7 (preliminary)
200 - 400	39.7	15.9	15.9	589.2	343.3	2548.0	190.2
400 - 600	23.1	1.1	17.3	156.7	74.7	830.0	75.7
600 - 800	11.4	6.6	13.9	77.5	37.4	223.0	48.2
800 - 1000	14.1	1.1	8.1	45.3	42.7	225.0	13.2
1000 - 1200	11.0	3.3	8.1	58.1	42.3	170.0	11.2
1200 - 1400	1.6	6.6	9.7	38.5	21.2	139.2	27.6
1400 - 1600	0.0	4.4	4.8	9.6	2.6	31.2	0.0
1600 - 1800	3.1	1.1	0.0	1.6	0.0	0.0	0.0
1800 - 2000	0.0	0.0	0.0	1.6	0.0	2.4	0.0
Beyond 2000'	0.0	0.0	0.0	0.0	1.3	0.0	0.0

TABLE 5. ADJUSTED FRAGMENT COUNTS

TABLE 6. AVERAGE NO. OF FRAGMENTS PER PROJECTILE EXPLOSION

Fragments Per Explosion

Range Interval (ft)	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Test No. 5	Test No. 6	Maxima Tests 1-6	Test No. 7 (preliminary)
200 - 400	3.0555	1.7615	1.3244	8.9267	5.2808	8.0126	8.9267	13.5851
400 - 600	1.7807	0.1216	1.4401	2.3747	1.1496	2.6101	2.6101	5.4096
600 - 800	0.8794	0.7299	1.1578	1.1743	0.5759	0.7013	1.1743	3.4419
800 - 1000	1.0884	0.1216	0.6715	0.6858	0.6569	0.7075	1.0884	0.9416
1000 - 1200	0.8465	0.3649	0.6715	0.8800	0.6514	0.5346	0.8800	0.7988
1200 - 1400	0.1209	0.7299	0.8058	0.5827	0.3257	0.4377	0.8058	1.9743
1400 - 1600	0.0000	0.4866	0.4029	0.1457	0.0407	0.0981	0.4866	0.0000
1600 - 1800	0.2419	0.1216	0.0000	0.0243	0.0000	0.0000	0.2419	0.0000
1800 - 2000	0.0000	0.0000	0.0000	0.0243	0.0000	0.0075	0.0243	0.0000
Beyond 2000'	0.0000	0.0000	0.0000	0.0000	0.0204	0.0000	0.0204	0.0000

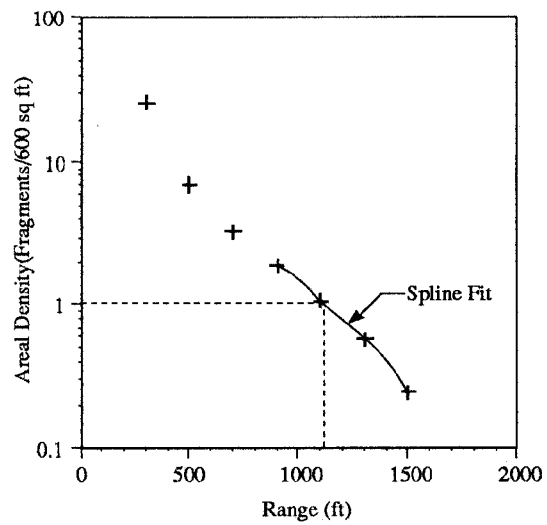# TABLE 6.
AVERAGE NO. OF FRAGMENTS PER PROJECTILE EXPLOSION

Range Interval (ft)	Pieces Per Explosion	Predicted No. of Fragments		Pseudo Trajectory-Normal Fragment Count		No. of Fragments Per 600 ft^2	
		(45% Explode)	(All Explode)	(45% Explode)	(All Explode)	(45% Explode)	(All Explode)
200 - 400	8.927	4017.0	8926.7	7316.3	16258.4	11.644	25.876
400 - 600	2.610	1174.5	2610.1	3299.3	7331.7	3.151	7.001
600 - 800	1.174	528.4	1174.3	2124.7	4721.6	1.449	3.221
800 - 1000	1.088	489.8	1088.4	1596.3	3547.4	0.847	1.882
1000 - 1200	0.880	396.0	880.0	1106.5	2459.0	0.480	1.067
1200 - 1400	0.806	362.6	805.8	710.5	1579.0	0.261	0.580
1400 - 1600	0.487	219.0	486.6	347.9	773.1	0.111	0.246
1600 - 1800	0.242	108.8	241.9	128.9	286.5	0.036	0.080
1800 - 2000	0.024	10.9	24.3	20.1	44.7	0.005	0.011
Beyond 2000	0.020	9.2	20.4	9.2	20.4	-	-

TABLE 7. SAMPLE CALCULATION OF FRAGMENT AREAL DENSITIES FOR A STACK OF 1000 TNT-FILLED CARTRIDGES

FIGURE 13. ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT^2 FOR A STACK OF 1000 TNT-FILLED CARTRIDGES
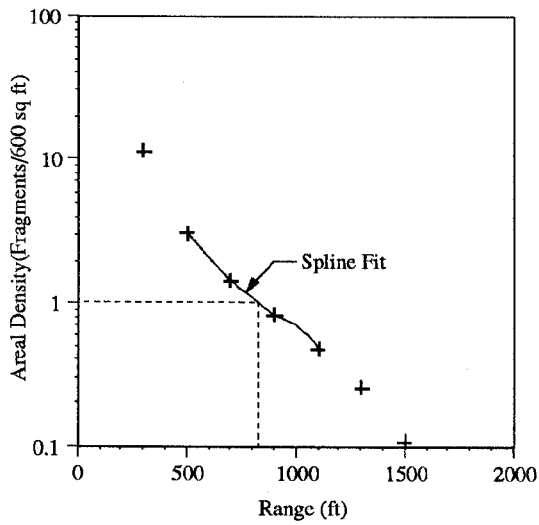
Assumes 45% of Projectiles Explode

Assumes 100% of Projectiles Explode

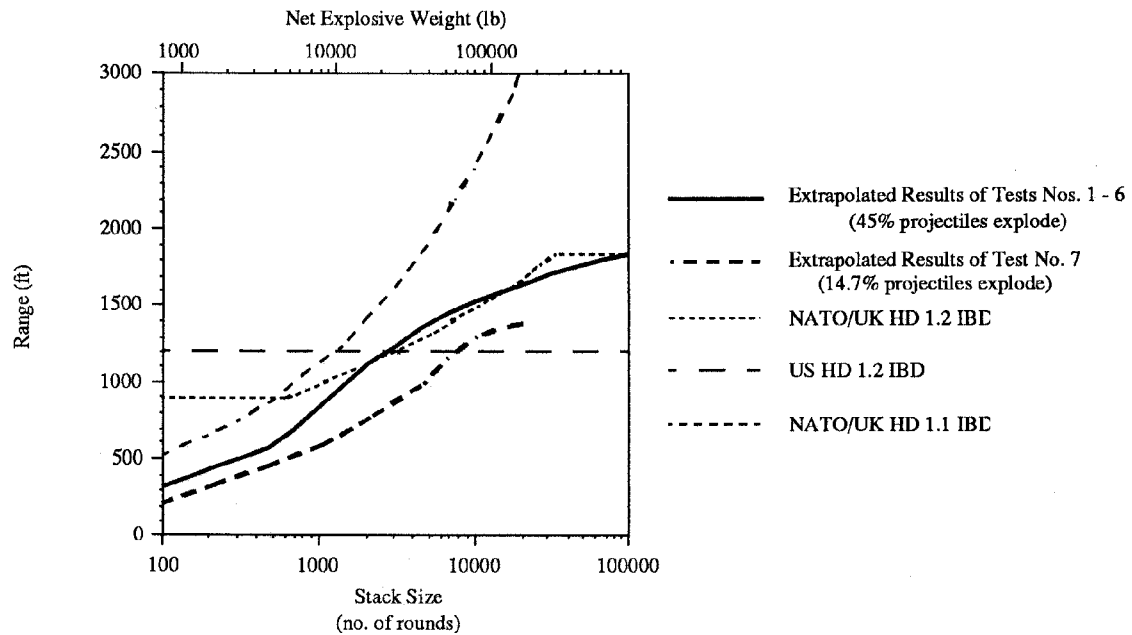FIGURE 13. ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT^2 FOR A STACK OF 1000 TNT-FILLED CARTRIDGES

TABLE 8. ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT^2

| Stack Size (no. of rounds) | Range to Exceed 1 Fragment per 600 ft^2 (ft) | | | |
| | Cartridges Containing TNT | | Cartridges Containing Composition B | |
	(45% explode)	(100% explode)	(14.7% explode)	(100% explode)
100	325	447	205	530
147	385	503	279	601
215	442	566	347	709
316	499	706	407	792
464	566	838	468	880
681	681	988	526	991
1000	825	1120	596	1186
1468	977	1267	709	1314
2154	1099	1360	789	1367
3162	1240	1448	872	(note)
4642	1352	1524	988	(note)
6813	1441	1602	1175	(note)
10000	1521	1666	1310	(note)
14678	1580	1720	1368	(note)
21544	1670	1778	(note)	(note)
31623	1749	1817	(note)	(note)
46416	1773	1850	(note)	(note)
68129	1827	1894	(note)	(note)
100000	1848	1902	(note)	(note)

NOTE: No fragments were found beyond the 1400 ft range after test no. 7. Thus there is no basis for predicting fragment density as a function of stack size beyond this range.
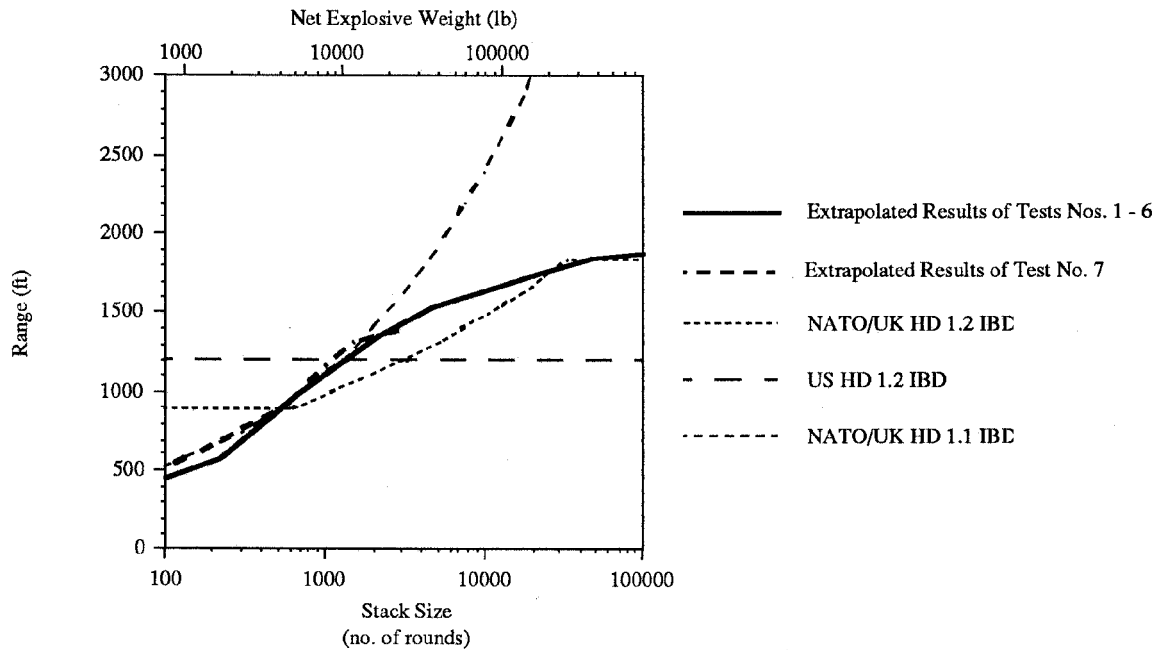
TABLE 8.
ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT^2

FIGURE 14.
COMPARISON OF ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT² WITH CURRENT Q-D REQUIREMENTS ASSUMING ONLY INDICATED PORTION OF THE PROJECTILES EXPLODE

FIGURE 14. COMPARISON OF ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT² WITH CURRENT Q-D REQUIREMENTS ASSUMING ONLY INDICATED PORTION OF THE PROJECTILES EXPLODE

FIGURE 15. COMPARISON OF ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT² WITH CURRENT Q-D REQUIREMENTS ASSUMING ALL PROJECTILES EXPLODE

FIGURE 15. COMPARISON OF ESTIMATED RANGES TO EXCEED 1 FRAGMENT PER 600 FT² WITH CURRENT Q-D REQUIREMENTS ASSUMING ALL PROJECTILES EXPLODE

CONCLUSIONS

A fire in an exposed stack of M1 105mm cartridges results in a series of explosions over a period of approximately one hour. Times to first reaction have all been in excess of 14 minutes. Following the first explosion the frequency of explosions builds up rapidly with time and then reduces at a lower rate towards the end of the event.

The most violent reactions are explosions of some of the projectiles in the stack. These explosions often produce relatively large high velocity fragments that have ranges approaching and possibly exceeding 2000 ft. The remaining projectiles either react in a manner that does not fragment the case (i.e., burning) or they are thrown clear of the fire and do not react.

The portion of the projectiles in the stack that explode and the manner in which they fragment is influenced by the main fill explosive. For cartridges containing TNT as the projectile main fill, approximately 25% to 45% of the projectiles explode. These projectiles react individually (vice "sympathetic" reactions of multiple rounds) and generally produce a relatively small number of large fragments. This type of fragmentation indicates reaction levels that are less violent than detonation. In contrast, less than 15% of the projectiles exploded in the one test conducted to date using cartridges filled with Composition B. Additionally, more than half of the fragments from this test appeared to have been produced by projectile detonation(s).

Fragments are dispersed randomly in azimuthal angle and the fragment density decreases rapidly with range from ground zero. Projectile body fragments are the primary contributor to far-field fragment hazards. The fragments produced by the propelling charges are generally thin light fragments that, with only a few exceptions, are limited to a range less than 600 ft.

DISCUSSION

The preceding analyses are based on a relatively limited number of tests. Additionally, the results of the analyses include extrapolations to stack sizes that are several orders of magnitude larger than the sizes tested. Thus consideration should be given to the limitations and uncertainties that are inherent in the test data and analysis method when interpreting the analyses results; particularly the predicted behavior for very large stacks. However, based on the results summarized in Figures 14 and 15:

> a. Cartridges containing TNT pose a greater fragment hazard than those containing Composition=B if it is assumed that the percentages of projectile explosions observed in these tests (i.e., approximately 25% to 45% for rounds containing TNT, approximately 15% for rounds containing Composition B) are representative of larger stack sizes. However, at present it is speculated that the percentage of projectile explosions observed in test no. 7 may have been misleadingly low due to the removal of the nose fuzes from the projectiles prior to the test. A follow-up test using cartridges containing Composition B and assembled with shipping plugs is planned to

help assess the influence of fuze well confinement.

b. If it is assumed that all of the projectiles in the stack may explode (i.e., worst case), there is little difference in the fragment hazard associated with the respective test item configurations. Intuitively it is expected that, given an equal number of projectile explosions, cartridges containing Composition B may create a slightly greater number of fragments due to the detonation of some projectiles. However the recovery data from test no. 7 suggest that the smaller fragments created by the detonation reactions tend to have less range than the larger fragments created by less violent reactions. Thus the net effect appears to be that, relative to TNT-filled cartridges, cartridges containing Composition B may produce slightly higher fragment densities at shorter ranges but slightly lower densities at longer ranges. This is consistent with the behavior predicted in Figure 15.

c. Both the US and NATO/UK HD 1.2 IBD requirements are conservative for stacks smaller than approximately 1000 rounds if it is assumed that the percentage of projectiles that will explode is consistent with these tests. The NATO/UK IBD requirements appear to be reasonable for larger stack sizes; however, the US requirements are optimistic for stacks larger than approximately 3000 rounds of TNT-filled cartridges. If the percentage of projectiles that explode is greater than that observed in these tests, the NATO/UK requirements may also be optimistic for larger stack sizes.

d. The predicted 1/600 ranges become asymptotic with range for very large stacks. This is consistent with the intuitive expectation that there is some maximum fragment range associated with worst-case conditions (i.e., maximum initial fragment velocity, minimum drag, optimum trajectory, maximum ricochet, etc.) within which all fragments must be contained, regardless of the number of fragments generated.

e. The NATO/UK HD 1.1 IBD follows the predicted 1/600 ranges for stacks smaller than approximately 3000 rounds. However, it diverges significantly with increasing stack size. This is expected since the HD 1.1 IBD requirements are governed primarily by blast and thus the HD=1.1 IBD continues to increase exponentially with increasing total NEW.

The analyses of fragment hazards have been based only on final fragment densities resulting from the cumulative buildup of far-field fragments throughout each test. One of the distinguishing features of a HD 1.2 event relative to a HD 1.1 event is the prolonged period of time over which reactions occur. Table 9 gives the elapsed times following the initial explosion at which 20%, 50%, and 100% of the explosions occurred in each test. It can be seen that once reactions begin, their frequency and the resultant fragment hazard increase unpredictably and rapidly. It is therefore considered inadvisable to consider any period following the first explosion during which reduced hazardous radii might be inferred.

There is an initial period of roughly 15 minutes before any reaction occurs. However, the

time to first reaction will vary with many factors (e.g., the amount of fuel available, packaging materials, caliber of rounds (thermal mass), and the thermal sensitivity of the explosives used). Thus, time for emergency response measures and evacuation of the area may be limited to less than 15 minutes. For these reasons, automatic fire detection and alarm systems are important features for maximizing the time available for safe evacuation. Additionally, the use of automatic drench systems may be the only safe means of fire fighting. Automatic drench systems may also mitigate (or eliminate) the fragment hazard if the fire can be extinguished early in the event.

TABLE 9. TIMES IN WHICH 20%, 50%, AND 100% OF EXPLOSIONS HAVE OCCURRED

Time Following Initial Explosion (Min:Sec)

	$T_{20\%}$	$T_{50\%}$	$T_{100\%}$
Test 1	01:34	09:20	30:29
Test 2	02:47	09:19	18:22
Test 3	12:14	19:41	41:52
Test 4	08:35	14:39	40:20
Test 5	04:20	07:08	23:05
Test 6	09:54	14:36	47:43
Test 7	04:05	08:23	20:20

TABLE 9. TIMES IN WHICH 20%, 50%, AND 100% OF EXPLOSIONS HAVE OCCURRED

If it is conjectured that HD 1.2 items will generally react consistently with most of the items in a stack producing similar sizes and numbers of fragments, then the associated fragment hazards would be dependent primarily on the number of rounds in the stack and their fragmentation characteristics; not the total NEW of the stack. Evidence from tests on 40mm ammunition seems to support this[14]. Thus, one approach for handling HD 1.2 Q-D's for items that fragment (vice propulsion) may be to establish several categories of munitions, as done in NATO/UK by range of caliber, and then define Q-D relationships for each category based on number of rounds. Characteristics that might be considered in establishing categories include caliber, principal reaction type (e.g., detonation or deflagration), and structural features (e.g., thick-wall or thin-wall).

Although intact projectiles have been recovered several hundred feet from the ground zero, there have been very few occasions in which a round was thrown more than 50 ft from the burning stack and then exploded. There have been no instances in which a round was thrown more than 150 ft from the fire and then exploded. Thus, in calculating quantity-distances, it does not appear that the post-impact explosion of lobbed rounds will contribute appreciably to overall fragment ranges.

As may be expected in an event in which the orientation of the rounds in the stack is destroyed after the first one or two explosions, there is no noticeable directional trend in the

far-field fragmentation.

The purpose of this effort was to characterize the effects from fires in exposed stacks of ammunition. It is expected that storage inside buildings will tend to mitigate the far-field fragment hazards due to the containment effects of the structure. However it is also quite possible that a greater percentage of the items in the stack may react as a result of the containment. Thus, if the structure is breached, fragment areal densities in the immediate vicinity of the structure may be somewhat greater. A program of work to investigate the effects of the initiation of HD 1.2 ammunition in structures is described in another paper at this seminar[15].

REFERENCES

1.   Gould. M.J.A., et al, "Trial to Determine the Consequences of the Accidental Ignition of Stacks of Hazard Division 1.2 Ammunition", Minutes of the Twenty-Fifth DOD Explosives Safety Seminar, August 1992.

2.   Henderson, J., "Joint Australian/UK Stack Fragmentation Trials Phase 4 Preliminary Report", Minutes of the Twenty-Fourth DOD Explosives Safety Seminar, August 1990.

3.   Henderson, J., Rees, N.M.J., "Joint Australian/UK Stack Fragmentation Trials Phase 3 Preliminary Report", Minutes of the Twenty-Third DOD Explosives Safety Seminar, August 1988.

4.   Henderson, J., et al., "Joint Australian/UK Stack Fragmentation Trials Phase 2 Report", Minutes of the Twenty-Second DOD Explosives Safety Seminar, August 1986.

5.   Bowman, F., et al., "Joint Australian/UK Stack Fragmentation Trials Phase 1 Report", Minutes of the Twenty-First DOD Explosives Safety Seminar, August 1984.

6.   Roger, M., "Assessment of Hazardous Areas When Storing HD 1.1. Ammunition in French "IGLOO TYPE" Magazines", Minutes of the Twenty-Fifth DOD Explosives Safety Seminar, August 1992.

7.   Swisdak, M.M., "Hazards Produced By Explosions Inside Earth-Covered Igloos", Minutes of the Twenty-Fifth DOD Explosives Safety Seminar, August 1992.

8.   Joachim, C., "Shallow Underground Tunnel/Chamber Explosion Test", Minutes of the Twenty-Fourth DOD Explosives Safety Seminar, August 1990.

9.   Joachim, C., "Accidental Detonations In Underground Munitions Storage Magazines: Predictions of Cover Rupture Pressure", Minutes of the Twenty-Fourth DOD Explosives Safety Seminar, August 1990.

10.   Joachim, C., "Ejecta Hazard Ranges From Underground Munitions Storage Magazines", Minutes of the Twenty-Fourth DOD Explosives Safety Seminar, August 1990.

11.   United Nations Recommendations on the Transport of Dangerous Goods, Tests and Criteria, ST/SG/AC.10/11 Current Revision.

12.   Swisdak, M.M., and Rye, K.W., Hazard Division 1.2 Tests: Instrumentation Results and Interpretation, NSWCDD/TR-93/218, NSWCDD, Dahlgren, VA, 9 March 1994.

13.   Swisdak, M.M., Jr., "Procedures for the Analysis of the Debris Produced by Explosion Events", Minutes of the Twenty-Fourth Explosives Safety Seminar, August 1990.

14.   Information on the Fire of 14th May 1985 in Norway in a Semi-Trailer Loaded with 40mm HE-T Ammunition - Report from External Stack Fire Test, NATO AC/258-NO (MG) IWP 80, 24 April 1986.

15.   Gould, M.J.A., and Goold, I.I., "Current Proposals for the Determination of the Consequences of the Accidental Initiation of Stacks of Hazard Division 1.2 Ammunition in Structures", (for presentation at the Twenty-Sixth Explosives Safety Seminar, August 1994).